Interplay of Direct and Indirect Searches for New Physics[1]

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Abstract. We report recent work on the interplay of collider and flavour physics regarding the search for physics beyond the Standard Model.

INTRODUCTION

At the beginning of the LHC era, the search for new degrees of freedom beyond the Standard Model (SM) is within the main focus of particle physics. In principle, there are two ways to search for possible new degrees of freedom. At the high-energy frontier one tries to produce and observe them directly, while at the high-precision frontier one analyses their indirect virtual effects within flavour or electroweak observables.

Flavour changing neutral currents (FCNCs) test the SM at the one-loop level and offer complementary information about the SM and it extensions. They are sensitive for the product of mixing angles and mass splittings between possible new heavy particles while within the direct search the masses can be measured directly.

Within supersymmetric extensions of the SM, the measurement of the flavour structure is directly linked to the crucial question of the supersymmetry-breaking mechanism. Thus, the flavour sector is important in distinguishing between models of supersymmetry. This example demonstrates the obvious complementary nature of flavour physics and high-p_T physics. At the LHC, direct searches for supersymmetric particles are essential for establishing the existence and the nature of new physics (NP) beyond the SM. On the other hand, flavour physics provides an important tool with which fundamental questions regarding the structure of this NP, such as how supersymmetry is broken, can be addressed.

None of the dedicated flavour experiments in the last decade has observed any unambiguous sign of new physics yet [1], in particular there are no $\mathcal{O}(1)$ NP effects in any FCNC process [3]. Also the first results of the LHCb experiment [4] are in full agreement with the CKM theory of the SM. This experimental fact implies the infamous flavour problem of NP, namely why FCNC processes are suppressed. It has to be solved in any viable NP model. The hypothesis of minimal flavour violation (MFV) [2], i.e. that the NP model has no flavour structures beyond the Yukawa couplings, solves this problem formally. A completely anarchic flavour structure, on the other hand, would require that the scale of NP be tens of TeV, such that NP effects decouple [5]. In between these two extremes, non-minimal flavour violation can still be compatible with the present data (see below) because the flavour sector has been tested only at the 10% level in $b \to s$ transitions.

From theoretical arguments we expect NP to become apparent at the $\mathcal{O}(1)$ TeV scale, while flavour constraints naturally seem to point to a much higher scale. In the case of supersymmetry in particular, flavour constraints limit sparticles from being very light. On the other hand, ATLAS and CMS searches with about 1 fb^{-1} of data at 7 TeV [6] already put lower limits on squark and gluino masses of roughly $m_{\tilde{q},\tilde{g}} \gtrsim 1.1$ TeV for $m_{\tilde{q}} \simeq m_{\tilde{g}}$, thus beginning to probe the preferred regions of simple SUSY realizations like the CMSSM. It is worth noting, however, that the limits on the gluino mass from the current LHC run become much weaker when $1^{st}/2^{nd}$ generation squarks are somewhat heavier—as indeed preferred by the flavour constraints. Sub-TeV stops and electroweak gauginos are still allowed.

The CERN working group "Interplay of Collider and Flavour Physics" [7] addresses the complementarity and synergy between the LHC and the flavour factories within the new physics search. It is a follow-up of the two recent

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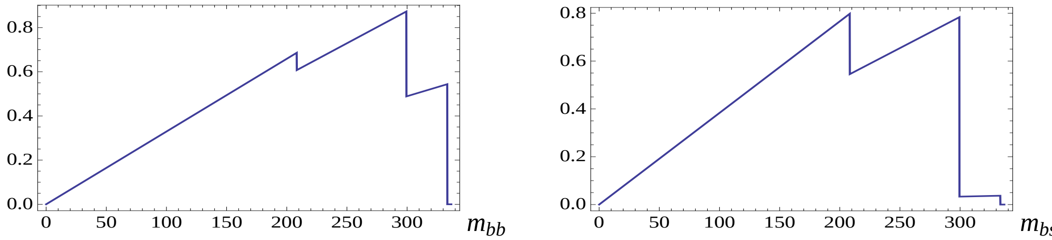

FIGURE 1. Left: Differential distributions $d\mathrm{BR}(\tilde{g} \to b\bar{b}\tilde{\chi}_1^0)/dm_{bb} \times 10^4$ as a function of $m_{bb} = \sqrt{(p_b + p_{\bar{b}})^2}$. Right: $d(\mathrm{BR}(\tilde{g} \to bs\tilde{\chi}_1^0)/dm_{bs}$ as a function of m_{bs} (the sum over the charges is shown: $\mathrm{BR}(\tilde{g} \to b\bar{s}\tilde{\chi}_1^0)$ + $\mathrm{BR}(\tilde{g} \to \bar{b}s\tilde{\chi}_1^0)$).

CERN workshop series "Flavour in the Era of the LHC" [8] and "CP Studies and Non-Standard Higgs Physics" [9] at the interface of collider and flavour physics and experiment and theory.

In this contribution, we report on some recent work on this interplay. For lack of space we focus on two examples, and we apologize for the omission of other relevant work.

FLAVOUR-VIOLATING SQUARK DECAYS

Flavour-violating high- and low-energy observables are governed by the same parameters in supersymmetric models. A particularly important question is whether the soft SUSY breaking parameters can have additional flavour structures beyond the well-known CKM. Recently, it was shown [10] that, in view of the present flavour data, flavour-violating squark and gluino decays can be typically of order 10% in the regions of parameter space where no or only moderate cancellations between different contributions to the low energy observables occur [2]. This observation has an impact on the discovery strategy of squarks and gluinos as well as on the measurement of the underlying parameters at the LHC. For example, in mSUGRA points without flavour mixing one finds usually that the left-squarks of the first two generations as well as the right squarks have similar masses. However, large flavour mixing implies that there is a considerable mass splitting as can be seen. Therefore, the assumption of almost degenerate masses should be reconsidered and the possibility of sizeable flavour-changing squark and gluino decays taken into account.

An important part of the decay chains considered for SPS1a' and nearby points are $\tilde{g} \to b\tilde{b}_j \to b\bar{b}\tilde{\chi}_k^0$ which are used to determine the gluino mass as well as the sbottom masses or at least their average value if these masses are close [11]. In the latter analysis, the existence of two b-jets has been assumed stemming from this decay chain. In this case the two contributing sbottoms would lead to two edges in the partial distribution $d(\mathrm{BR}(\tilde{g} \to b\bar{b}\tilde{\chi}_1^0)/dm_{bb}$ where m_{bb} is the invariant mass of the two bottom quarks. As can be seen from the left plot of Figure 1, there are scenarios where more squarks can contribute and consequently one finds a richer structure, e.g. three edges in the example shown. Such a structure is either a clear sign of flavour violation or the fact that the particle content of the MSSM needs to be extended. The edge analysis allows both options. The differential distribution of the final state $bs\tilde{\chi}_1^0$ shows a similar structure where the edges occur at the same places as in the $b\bar{b}$ spectrum but with different relative heights, see right plot of Figure 1. This gives a non-trivial cross-check on the hypothesis of sizeable flavour mixing. Clearly a detailed Monte Carlo study will be necessary to see with which precision one can extract information on these edges.

LEPTON-FLAVOUR VIOLATION IN 5D SUSY-GUTS

In supersymmetric models with a GUT-sized extra dimension, where both the Higgs fields and the SUSY breaking hidden sector are localized on a 4D brane, exponential wave function profiles of the matter fields give rise to hierarchical structures in the Yukawa couplings and soft terms. Such structures can naturally explain hierarchical fermion masses and mixings, while at the same time alleviating the supersymmetric flavour problem. This idea and its phenonmenological consequences have been discussed in the literature mostly on the qualitative level, see

[2] If one allows for larger new physics contributions, e.g. the same order as the SM contributions, in the flavour observables, then even flavour-violating branching ratios of up to 40% are consistent with the present data.

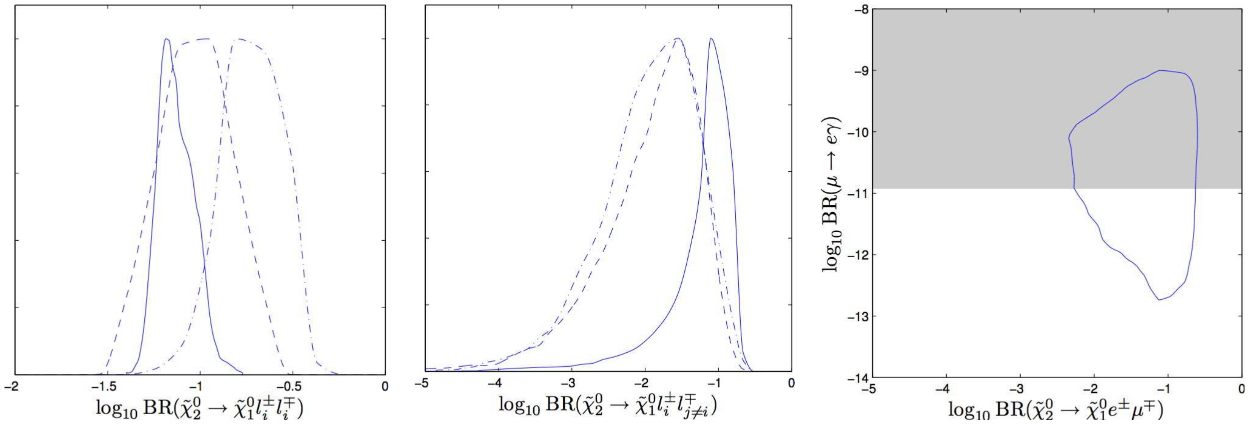

FIGURE 2. Probability densities for $\tilde{\chi}_2^0$ decays in a mixed brane-radion scenario, from [13]. The left and middle plots show $\mathrm{BR}(\tilde{\chi}_2^0 \to l_i l_j \tilde{\chi}_1^0)$ with plain, dashed and dash-dotted lines corresponding to $l_i l_i = ee$, $\mu\mu$, $\tau\tau$ (left) and $l_i l_j = e\mu$, $e\tau$, $\mu\tau$ (middle), respectively. On the right, 95% credible region in the $\mathrm{BR}(\mu \to e\gamma)$ versus $\mathrm{BR}(\tilde{\chi}_2^0 \to e\mu\tilde{\chi}_1^0)$ plane.

e.g. [12]. Very recently a detailed numerical study for this class of models was performed in [13] for two sources of supersymmetry breaking, radion mediation and brane fields.

It was found that the most stringent constraints come from the bounds on lepton flavour violation, in particular from $\mathrm{BR}(\mu \to e\gamma)$. The favourable regions of parameter space that satisfy the experimental constraints were examined with respect to their LHC phenomenology. They generically feature heavy squarks and gluinos beyond the current LHC limit of $m_{\tilde{q}} \approx m_{\tilde{g}} \gtrsim 1.1$ TeV [6]. The 5D setup leaves its imprints in the slepton mass matrices, which can lead to slepton mass splittings and interesting lepton-flavour violating SUSY decays at the LHC. The proliferation of unknown $\mathscr{O}(1)$ coefficients that occurs in this class of models necessitates a probabilistic approach to numerical predictions. As an example, Figure 2 shows probability density distributions of $\tilde{\chi}_2^0 \to l^\pm \tilde{l}^\mp \to l^\pm l^\mp \tilde{\chi}_1^0$ decays for a mixed brane-radion mediation scenario. The dilepton signature is often regarded as a gold-plated channel as it allows to obtain information on the neutralino and slepton masses from kinematic distributions. As can be seen, here dileptons with mixed flavours can have a sizeable rate. Extracting information from kinematic edges with flavour splitting and mixing has recently been studied in detail [14].

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